Table 1: Obtained laser diode characteristics

	Maximum power [W]	Electric power (0.4 W output at 2 A) [W]	Slope efficiency [W/A]	Threshold	Active area [cm^2]
Active MMI	0.7	3	0.3	130 mA (0.7 kA/cm^2)	1.8×10^{-4}
Regular	0.4	5	0.3	60 mA (1 kA/cm^2)	6×10^{-5}

Acknowledgment: A part of this work was supported by NEDO. The authors would like to thank H. Melchior of the Swiss Federal Institute of Technology, and M. Mizuta, I. Mito, T. Torikai, and S. Sugou for their encouragement.

30 January 2002

Electronics Letters Online No: 20020362

DOI: 10.1049/el:20020362

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LTCC-MLC chip-type balun realised by LC resonance method

C.W. Tang and C.Y. Chang

A multilayer ceramic balun designed in the 2.4 GHz ISM band frequency is presented. A multilayer structure to realise the low temperature co-fired ceramic (LTCC) balun is proposed. This type of balun comprises an embedded capacitor and meandered or spiral coupled lines. The use of an LC resonator can shrink the length of a coupled transmission line and can be designed very easily to have various balanced output port impedances. Excellent performance of phase and amplitude balance may be achieved by the proposed method. Measured results of the LTCC-multilayer ceramic (MLC) balun match well with the computer simulation.

Introduction: The miniaturisation of RF telecommunication devices for portable and battery-powered applications, and for size, weight, cost, and power consumption reduction, is now essential. To realise a high-performance RF front-end for wireless applications, the low temperature co-fired ceramic (LTCC) multilayer ceramic (MLC) technology is widely used since it is suitable for the realisation of integrated passive components and for interconnection with active devices. Among passive RF components used in modern wireless communications, the balun is one of the most important components since it can be used to realise balanced mixers, amplifiers, multipliers, and phase shifters. Many kinds of balun have been proposed [1–4]. However, for different reasons, these baluns cannot properly fit the requirements described above. In contrast, the LTCC balun may meet the requirements.

We previously proposed a stepped impedance method [5] to realise the LTCC-MLC balun that uses various impedance ratios of a multi-section coupled line to shorten the length of a quarter wavelength coupled stripline. The balun in [5] shows broader bandwidth of amplitude balance. However, if the thickness of each layer is limited owing to process limitations, the size of the LTCC-MLC balun proposed in [5] is limited accordingly. In this Letter we propose an LC resonance method that overcomes the above problem. Using the LC resonator, the length of a coupled stripline can be shortened, and the limitation of layer thickness can also be loosened significantly. In addition, the physical structure is simplified compared to the balun in [5]. The multilayer structure is proposed to realise the so-called resonance method chip-type LTCC balun.

This newly proposed balun shows better phase balancing and looser processing control. The calculated and measured response of the proposed LTCC-MLC balun shows superior performances.

Design method: There are several methods to shorten the transmission line [5–9]. Here, we propose the LC resonance method to construct the LTCC-MLC balun.

Fig. 1 shows the multilayer structure to realise the proposed LTCC-MLC balun. A broadside coupled line in parallel with an embedded capacitor forms a LC resonator. To shrink the size, the layout of the coupled line can be spiral or meandered shape as shown in Fig. 1. Since the structure is symmetric, the centre plane of the circuit can be approximately equivalent to an electric wall at the centre frequency. It can realise the balanced output characteristics easily. The equivalent circuit of the proposed LTCC-MLC balun is shown in Fig. 2. To greatly reduce the size of the LTCC-MLC balun, the embedded capacitor in Fig. 1 could be moved to the dielectric layers below (or above) the coupled lines.

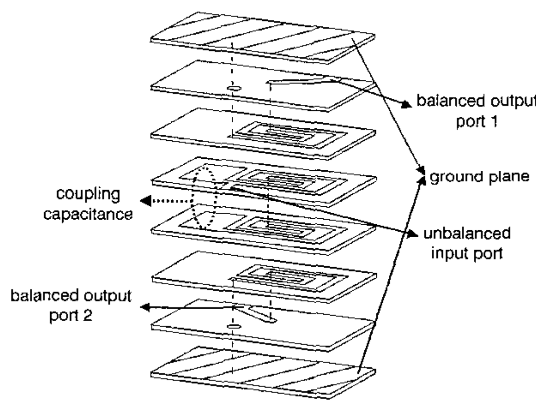

Fig. 1 *Proposed multilayer structure of LTCC-MLC balun*

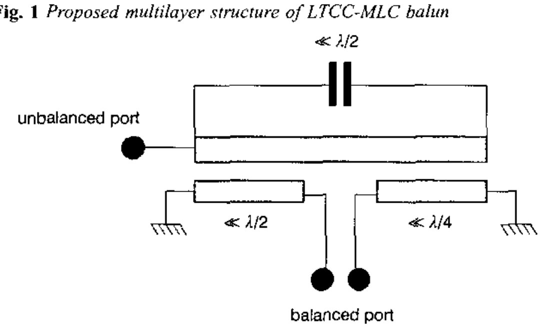

Fig. 2 *Equivalent circuit of LTCC-MLC balun*

This chip-type balun is designed to operate in the frequency range 2.34–2.54 GHz. The unbalanced input port impedance and each of the balanced output ports impedances are 50 Ω. The design procedures are as follows. First, we use the circuit simulator such as Libra or equivalent circuit software to obtain the initial design. Secondly, we use the three-dimensional electromagnetic (EM) simulator Sonnet to fine tune the final physical parameters. Finally, the transmission lines are meandered to shrink the balun further.

Simulated and measured results: This chip-type balun is designed to operate in the 2.4 GHz ISM band frequency. Fig. 3 shows a photograph of the fabricated LTCC-MLC balun. The designed chip-type balun is fabricated with a multiplayer configuration using 90 µm-thick ceramic sheets ($\varepsilon r = 7.8$) and a 10 µm-thick Ag metal pattern. The overall size of this balun is 3.2 × 1.67 × 0.8 mm. For the unbalanced input port impedance $R_1 = 50\,\Omega$ and for the balanced output port impedance $R_2 = 50\,\Omega$.

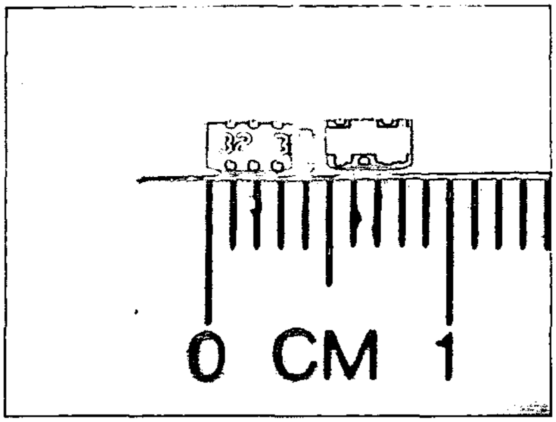

Fig. 3 *Photograph of fabricated LTCC-MLC balun of Fig. 1*

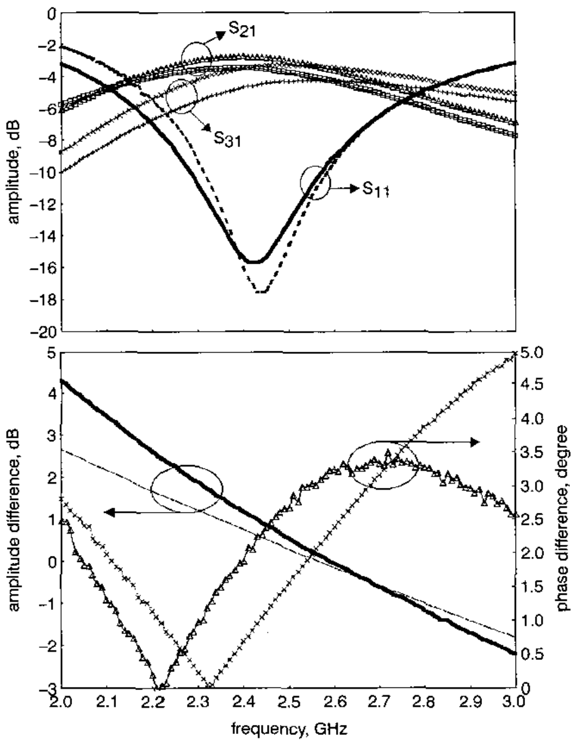

Fig. 4 *Simulated and measured results of LTCC-MLC balun of Fig. 1*

a Insertion loss and return loss
---- S11 simulated
--Δ-- S21 simulated
--×-- S31 simulated
—— S11 measured
—□— S21 measured
—|— S31 measured
b Amplitude and phase difference between balanced output
------ amplitude difference simulated
—— amplitude difference measured
--×-- phase difference simulated
—Δ— phase difference measured

The simulated (based on perfect conductor and lossless dielectric material) and measured results of this balun are shown in Fig. 4. The insertion loss and the return loss are less than −0.8 and −11.7 dB, respectively, for simulation, −2.1 and −11.3 dB, respectively, for measurement over the frequency range 2.34–2.54 GHz, as shown in Fig. 4*a*. The amplitude and phase imbalance between balanced outputs are within 1 dB and 1.9°, respectively, for simulation, 1.6 dB and 2.9°, respectively, for measurement over the operating frequency range as shown in Fig. 4*b*. The excellent match between the theoretical and measured results is obtained except for the insertion loss. The measured insertion loss is higher than the simulated result owing to the substrate loss and the metal loss not being included in the simulation for simulation speed consideration.

Conclusion: A novel LTCC-MLC balun has been developed. The design method and the equivalent circuit of this balun have been presented. The size of the balun was 3.2 × 1.6 × 0.8 mm, further reduction in size being possible. The measured performance was excellent over the ISM band frequency. The example balun was with unbalanced input impedance and each of the balanced output port impedances were 50 Ω. The designed chip-type balun was fabricated with multilayer configuration. The simulated and measured results show the validity of the proposed design method and the equivalent circuit of the balun.

Acknowledgment: This work was supported in part by the National Science Council, Taiwan, R.O.C. under grant NSC90-2213-E009-033.

5 November 2001
Electronics Letters Online No: 20020340
DOI: 10.1049/el:20020340

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Convergence analysis on iterative decoding of variable-length codes

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The convergence characteristics of iterative decoding of variable-length codes are discussed. It is observed that variable-length codes with greater redundancy perform better. This suggests that inserting more redundant information in the source-coded bits would be helpful in enhancing the overall performance when iterative decoding is employed.